# Using the Literature: Reference Networks, Reference Contexts, and the Social Structure of Scholarship

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*Networks of citations among the papers on a research topic reflect the structure of scholarship on that topic. Reference-network data for research areas from several disciplines show substantial variation in the structure of scholarship, ranging from the frequent and disproportionate citation of recent work to the frequent and disproportionate citation of foundational documents. The variation is inconsistent with the pattern expected of a simple physical sciences–behavioral sciences–humanities dimension. Citation-context analyses of references in the networks of various fields suggest that variation in network structure is due in part to differences in why authors cite their colleagues' work: Disproportionate citation of foundational documents occurs when authors cite papers as examples of perspectives or general approaches rather than as support for specific points. Differences in use patterns for citations can help us understand other differences among scholarly communities.*

An important issue for the sociology of science and knowledge is the relationship between foundational and current scholarship. Discussions of this issue often compare two prototypical structures, each exhibiting a distinctive combination of intellectual and social patterns. In the first, scholars focus on recently published research while tending to ignore foundational work. This structure exemplifies Whitehead's (1917) famous dictum: "[A] science which hesitates to forget its founders is lost" (p. 115). It displays a high level of "obliteration by incorporation" (Garfield 1977; Merton 1967) in which current research so thoroughly incorporates the scholarly achievements of the past that there is no need to acknowledge original sources. In fields with this structure, scholars purportedly build on recently reported findings and procedures, and the time between the announcement of a new finding and its incorporation in subsequent work is short (Price 1970). Keen competition for priority and the presence of "invisible colleges" (Crane 1972) also seem to characterize this structure.

In the second prototypical structure, scholars focus on early work while tending to ignore recent publications. This structure exists when scholars pursue questions raised in classic texts or when exegesis is a prominent activity (Collins 1998:793–99; Hoffman and Schmidt 1997:116). In fields exhibiting this structure, scholars compete by offering new insights on long-standing issues or by showing how ideas in classic texts can elucidate new topics. Scholarship in these fields is alleged to be an individualistic enterprise, with

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low competition for priority (Fuchs 1992; Whitley 1984).[1] According to these characterizations, the structure that a scholarly community exhibits should be related to many other features of scholarly life, including how researchers organize and experience their everyday research activities.

Despite considerable speculation about variation between the extremes defined by these two structures, evidence is scanty and generally weak. I report results from a comparative analysis of research areas spanning the natural sciences, behavioral sciences, and humanities that employs two promising but little used techniques for studying such variation in structure. One, reference-network analysis, provides measures of the extent to which authors disproportionately cite recent or early work in a field. The other, citation-context analysis, enables the study of how authors use previous work; for example, whether they cite earlier papers to exemplify general themes or to support concrete results. How authors use each others' work can illuminate the temporal pattern of citations among papers in a particular field and suggest possible causes of variation between fields.

## THE PREVALENCE OF THE TWO STRUCTURES OF SCHOLARSHIP

Most of the evidence on the two prototypical structures comes from research on other issues that focused on disciplines or groups of disciplines. For example, studies of scholars' references to different types of scholarly documents show that journal articles receive the great majority of citations in the natural sciences, while monographs are more important in the behavioral sciences (Clemens et al. 1995; Griffith and Small 1983; Line 1981; Small and Crane 1979). Frequently cited works in the behavioral sciences tend to be older than frequently cited works in the natural sciences, and many of the former are books by "founding fathers" such as Marx, Freud, and Weber (Line 1981). Indeed, this pattern led Griffith and Small (1983) to speculate that a few elderly "charismatic documents" provide intellectual integration in the otherwise fragmented behavioral sciences (also see Alexander 1987). Griffith and Small also observed greater turnover among frequently cited natural science documents than among frequently cited behavioral science documents, and concluded that the natural sciences produce new methods and discoveries at a higher rate than do the behavioral sciences. In sum, discipline-level comparisons of frequently cited documents and authors suggest that the natural sciences are closer to the first of the two structures of scholarship, while the behavioral sciences exhibit a pattern closer to the second.

These discipline-level studies of citation patterns may not accurately portray differences in the structure of scholarship, however, because they do not gauge whether documents of different types and ages are overcited or undercited given the type and age distributions of citable documents (Cole, Cole, and Dietrich 1978; MacRae 1969). For example, behavioral scientists may cite monographs more often than natural scientists do because monographs make up a larger portion of the scholarly literature in the behavioral sciences; and different rates of growth of scholarly literatures may account for differences in the average age of cited documents. Unfortunately, thorny issues in defining disciplinary boundaries and challenging bibliographic problems preclude gathering adequate data on the types and ages of scholarly documents for entire disciplines (Gupta 1990). Thus, the evidence about variation in the structure of scholarship is inconclusive (Cole 1983:127). I overcome these difficulties by analyzing networks of citations—"reference networks"—for sets of scholarly documents in different disciplines.

## REFERENCE-NETWORK ANALYSIS

Important features of a research area's scholarly development can be revealed by graphing its reference network (Price 1965). A *reference-network graph* represents the citation ties among a set of chronologically ordered

[1] Each of these two structures has at one time or another been touted as superior, and struggles between the proponents of each type sometimes mark fundamental shifts in scholarship, as in the seventeenth-century "ancients versus moderns" debate (Jones 1961).

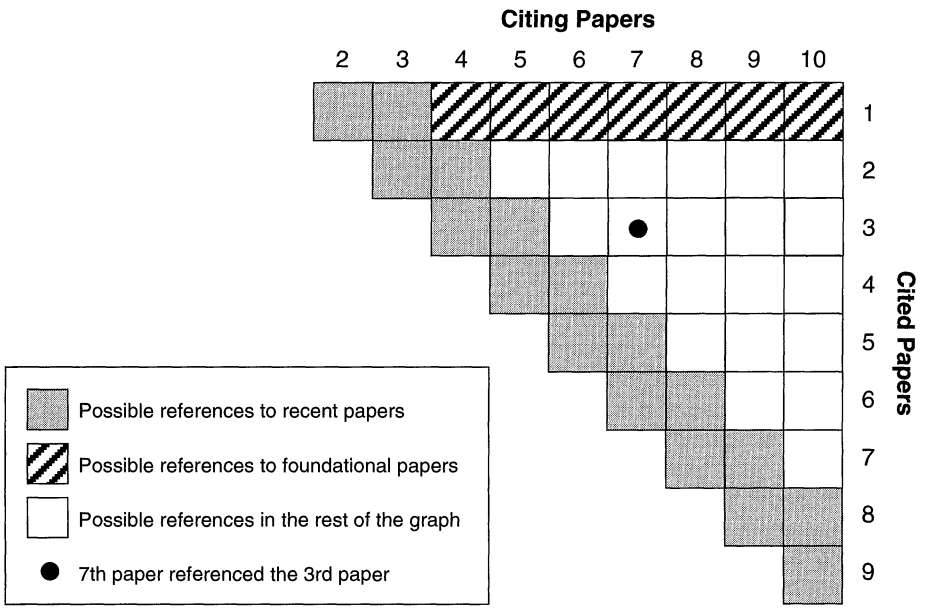


**Figure 1. Graph of a Hypothetical Reference Network**

papers[2] that are cross-classified as both citing papers (on the *x*-axis) and cited papers (on the *y*-axis). Figure 1 shows the citation ties that could exist among the papers in a hypothetical 10-paper research literature. Each column of cells in Figure 1 shows the references that a particular paper could make to previous papers. The left-most column, a single cell, represents a reference that the second paper in the literature *could* make to the first. If the second paper references the first, a dot is placed in the cell; otherwise the cell remains empty. The single dot in Figure 1, for example, indicates that the seventh paper referenced the third paper. Each row of cells in a reference-network graph shows whether a particular paper is cited by subsequent papers.[3] A pronounced row of dots in a reference-network graph indicates a frequently cited paper, and a pronounced column of dots indicates a paper containing many references to other works in the network (e.g., a literature-review paper).

A reference-network graph facilitates assessing disproportionate citation of subsets of papers. For example, when authors disproportionately cite recent papers, the dots will be concentrated along the graph's lower diagonal. In contrast, when authors disproportionately cite the earliest papers in the network, the dots will be concentrated along the top of the graph. Reference-network graphs facilitate the quantitative assessment of disproportionate citation by allowing one to compare the number of dots observed in a given subsection of the graph with the number that would be expected if citations were distributed randomly.

Price (1970) speculated that reference-network graphs would vary markedly across research fields. Specifically, he claimed that research areas[4] in the natural sciences would

[2] For brevity, I refer to published "documents" (articles, monographs, and chapters in edited books) as "papers."

[3] Here I follow Price (1970:7) and distinguish between references—which papers "send" to other papers—and citations—which papers "receive" from other papers. In many cases, however, the choice between these terms is arbitrary—the dot in Figure 1 can be called either a reference or a citation when considered without regard to its source or object—and the two terms are therefore often synonymous.

[4] A "research area" is typically smaller than a "specialty." For example, the sociological specialty "formal organizations" comprises several research areas, one of which is "organizational population ecology." While specialties usually have their own journals and scientific societies (Gieryn 1978; Whitley 1974), research areas

usually show a structure of scholarship in which recently published papers are overcited (relative to a pattern in which citations are randomly distributed). Price further speculated that in the humanities, the likelihood that a paper is cited would not be related to its age. In this pattern, which he dubbed an "archival" structure, early papers in a literature are as likely to be cited as recent ones. Like others (Alexander 1987; Merton 1968:27–30), Price expected research areas in the behavioral sciences to show structures intermediate between those in the physical sciences and the humanities. Finally, he believed that few if any research literatures would exhibit the structure of scholarship in which scholars tend to cite only early papers.[5]

No one has collected comparative reference-network data to assess these conjectures. This is surprising not only in light of the promise of such data for studying variation in structures of scholarship but also because of increasing skepticism about claims concerning differences among scholarly fields (Cole 1992; Gieryn 1995; Knorr-Cetina 1981; Latour and Woolgar 1979). I begin by presenting comparative reference-network data as a first step in filling this gap in our knowledge. After showing that knowledge structures vary substantially, I use citation-context analysis to show that the variation is related to differences in how scholars use each others' work. Together, these two forms of analysis suggest possible reasons for other differences among scholarly fields.

typically have fewer than 50 active participants (Hagstrom 1976:759), experience immigration and emigration of participants, and are rarely any researcher's sole focus (Gieryn 1978). Research areas sometimes span different specialties and may develop into specialties in their own right.

[5] Although Price speculated only about variation in the structure of reference-network graphs across research areas, a research area's structure can vary over time. Most speculation about this possibility has focused on changes that might occur when a vigorous research area becomes stagnant (Menard 1971:31–39), but changes would also be expected in the structure of reference networks when slowly growing fields suddenly get "hot" (Small 1980). Thus, the structure of a research area's reference network at a given point summarizes its development up to that point; it need not be a permanent feature.

## DATA AND METHODS

### *THE RESEARCH AREAS*

In selecting research areas, I sought areas reputed to be active centers of scholarly effort. To find them, I asked informants to identify such areas in their own disciplines (although none of these informants was active in the areas I chose, two worked on closely related topics). I chose areas of recent or current activity rather than historical cases to facilitate data collection and also so that I could contact active researchers in those areas for help.[6]

The labor-intensive nature of data collection limited the number of research areas I could study; for most areas I recorded and cross-classified references in hundreds of papers. I chose three research areas from the physical sciences, three from the behavioral sciences, and one from the humanities. In the physical and behavioral sciences, I sought both theoretical and empirical areas. The literatures of five of the areas I chose are very large; in order to balance depth of coverage of single areas with coverage of several areas, I stopped collecting data for these areas at a point when they had grown to 300 to 400 papers (this point varied from 16 years after the appearance of the initial paper on celestial masers to 51 years after the first paper on the Stroop effect).[7] Table 1 shows the research areas, their sizes, and the periods during which the papers in my analysis appeared.

A few comparisons of these areas' general characteristics sets the stage for my analyses (Appendix A presents brief histories and descriptions of the substantive foci of the seven areas). Journal articles constitute at

[6] Reference-network structures could be studied for entire disciplines, but because citation densities are much lower for disciplines than they are for narrower research areas, studies of disciplines would require much larger samples of papers.

[7] I collected the data for the seven areas in my analysis serially, starting with light-front physics and organizational population ecology. As a consequence, I ended the data collection for those two research areas at points when their cumulative literatures were smaller than the other areas in my study.

**Table 1. Descriptive Information on Papers in the Analysis**

| Research Area | Broader Discipline | Number of Papers | Years Covered |
|---|---|---|---|
| Celestial masers | Astronomy | 384 | 1965–1980 |
| Chiral separations | Chemistry | 393 | 1971–1987 |
| Light-front physics | Theoretical nuclear physics | 176 | 1949–1991 |
| Literary criticism on Toni Morrison's oeuvre | English literature | 309 | 1975–1993 |
| Organizational population ecology | Sociology | 140 | 1977–1993 |
| Rational expectations | Economics | 391 | 1961–1984 |
| Stroop effect | Psychology | 315 | 1935–1985 |

least 95 percent of the documents in five of the research areas: celestial masers, chiral separations, light-front physics, rational expectations, and the Stroop effect. Journal articles make up substantially lower proportions of the literary criticism on Toni Morrison (69 percent) and organizational population ecology (68 percent) areas, for which the remaining documents are almost all chapters in edited books. Monographs are scarce in all areas, least so in the literary criticism area where they constitute slightly less than 3 percent of the literature.[8]

The literary criticism and organizational population ecology areas are also distinct from the other areas in their referencing patterns. The median number of references per paper is between 15.5 and 18 for the other areas, but it is 46.5 for organizational population ecology and only 9 for the literary criticism papers. In addition, the median proportion of references in each paper that cite other papers in the network ranges from .33 to .41 for the other areas, but is only .21 for organizational population ecology and .05 for the literary criticism area, suggesting lower closure for those two literatures. Citations are less concentrated in the introductory and concluding paragraphs of the literary criticism papers than they are in the papers of the other areas. They are also more likely to occur in footnotes, which often address material peripheral to the main argument of an article, rather than to appear in the article's text.

Except for the literary criticism area, research papers tend to follow the standard "introduction–data and methods–results–conclusions" format, and most begin with an abstract. The literary criticism papers rarely have a formalized structure and never include an abstract. They frequently open with quotations from well-known literary figures, and often contain "playful" verbal elements such as puns, direct appeals to readers, and "point-last" argument structures (for an insightful analysis of these patterns, see Fahnestock and Secor 1994).

Manifestations of scholarly conflict also vary across the areas. In the literary criticism area, authors sometimes reject general approaches or single out other critics as having published superficial or flawed analyses. Similarly, authors of the Stroop-effect papers sometimes reject colleagues' interpretations or argue that their experimental methods are inadequate. Dispute is most striking in the rational expectations and organizational population ecology areas, where authors sometimes use dismissive titles to signal their opposition to an entire approach (e.g., "Combining Institutional Theory and Population Ecology: No Legitimacy, No History," "The Macroeconomics of Dr. Pangloss"). By contrast, negative comments in the three physical science areas were rare and generally tended to identify errors in computations or incomplete evidence rather than challenging fundamental assumptions underlying the whole enterprise.

### *Data Collection*

For each of the seven research areas, I compiled a list of published papers by consulting literature reviews and bibliographic sources such as *Psychological Abstracts* and the SCI/

[8] I included only the papers of the literary critics, not the novels they analyze.

SSCI *Permuterm Subject Index*. I also examined the reference lists of papers in each area to identify additional papers I should include. When I was unsure whether a paper belonged in a research area's list, I consulted an informant from that research area. I cannot claim to have identified every paper published on the topics I studied; obviously I missed papers that were never cited and that were not included in reviews or bibliographic sources. Nevertheless, I believe that I identified the documents that were at all consequential for the development of each area. I ordered the papers in each research area chronologically by date of publication,[9] and then recorded the references or footnotes in each paper that referred to other papers on the list. From these data I constructed reference-network graphs for each research area.

### *Analytic Methods*

Visual inspection is sometimes sufficient to discern whether recent or early papers are disproportionately cited in a reference network, but often this is not true. I therefore developed a method for (a) measuring the extent to which recent or early papers are disproportionately cited and (b) assessing the statistical reliability of any disproportionality. First, I had to specify which citations were to "recent" and "early" papers. I followed Price (1965) in defining the "R" most recent papers published before a given citing paper as composing the "research front" for that paper. If R equals 40 papers, for example, the possible references composing the research front for the 100th paper in a network would be those to the 60th to the 99th papers, the references in the research front for the 101st paper would be those to the 61st to the 100th papers, and so on. The research front for the entire network therefore consists of the set of possible references to the R most recent papers that could possibly be cited by each paper in the network. The illustration in Figure 1 sets R at 2—the cells in the research front are shaded gray.

Similarly, I define the first "F" papers in the network as the graph's "foundational papers"; the possible citations they might receive from later papers is the "foundational-papers section."[10] In Figure 1, F is set at 1, and cells in the foundational papers section are striped. Note that this section does not include the references that the R earliest papers might make to the F earliest papers; those possible references are part of the research front.

Specifying values for R and F partitions a reference-network graph into three sections: the research front, the foundational papers section, and the remainder of the graph (the unshaded and unstriped cells in Figure 1). If references were randomly distributed, they would be equally dense (within random variability) in all three sections of the graph. To construct independent measures of the extent to which references occur disproportionately in the research front or the foundational papers sections, I form ratios of the density of references in each of these two sections to the density of references in the remainder of the graph.[11] Thus, for example, a research-front (RF) reference-density ratio greater than 1.0 indicates that references are denser in the research front than they are in the remainder of the graph, and a foundational papers (FP) density ratio less than 1.0 indicates

[9] This is easier to do in fields in which journals have many issues annually or publish submission or acceptance dates. When a single issue of a journal contained more than one paper and dates of submission or acceptance were not available, I ordered them in order of appearance in the journal issue. In other cases of ambiguous temporal ordering, I ordered papers alphabetically by first author, although in a few cases I deviated from an alphabetical ordering if it produced a situation in which an "earlier" paper cited a "later" paper only because the alphabetical ordering was arbitrary.

[10] Because they constitute the beginning of a line of research, these papers are foundational for their respective research areas. They are not foundational for broader levels of scholarship, however. For example, although Hannan and Freeman (1977) is a foundational paper for organizational population ecology, it is obviously not foundational for the broader area of formal organizations or the discipline of sociology as a whole.

[11] The larger the reference-network graph, the larger the proportion of the graph constituted by the "remainder" section. In my analyses, the remainder section typically constitutes between 50 and 75 percent of a graph's cells.

that references are less dense in the foundational papers section than in the remainder. By comparing the research-front and foundational-papers sections to the remainder of the graph, I can ensure that the research-front and foundational-paper density measures are independent.

Simple tests for the proportion are inappropriate for assessing the statistical significance of deviations from 1.0 of the RF and FP density ratios because cells in reference-network graphs are not statistically independent observations. In particular, because the cells in each column of a reference-network graph are observations for a given citing paper, they are not independent of each other. To account for such dependence, I use a random-effects probit model to analyze the reference-network data (Guilkey and Murphy 1993; StataCorp 1999). Treating each cell in a reference-network graph as an observation, I regress whether the cell contains a reference (yes = 1, no = 0) on two binary independent variables: whether the cell is in the research-front section, and whether it is in the possible references to foundational-papers section (both coded yes = 1 and no = 0). Under this scheme, the remaining cells in the graph are the reference category, so significance tests for the coefficients of the two independent variables test whether cells in each of the two focal sections are statistically more or less likely to contain references than cells in the remainder section (for a similar modeling strategy, see Baldi 1998).

Specifying values for R and F is arbitrary. Price (1965) suggests setting R equal to 30 or 50 without justifying either choice. In the analyses reported below I set R to 40, but replicated my analyses with R set at values from 20 to 50. The patterns of over- or undercitation reported below are robust regardless of the value of R chosen. I examined results for values of F ranging from 20 to 50, although I never allowed F to exceed R.[12] I report results for F equal to 20, but the substantive results were stable regardless of the F-value chosen.[13]

[12] No one has previously singled out the prominence of citations to foundational papers as an important feature of a reference-network graph, so I had no guidance in choosing a value for F.

[13] Results for the other combinations of R and F values are available at http://www.sociology.ohio-state.edu/llh.

Reference networks contain two kinds of references that require special handling. First, papers sometimes cite forthcoming papers—these references are indicated in a reference-network graph by dots below the diagonal of the graph. I treated all such references as falling in the research front. Second, to control for the possible effects of differential presence of literature reviews across areas, I deleted all review papers, either as citing or cited papers, from my analyses. Review papers, which I operationally defined as those whose author(s) announced that their purpose was to summarize the existing literature on a topic rather than to present new results, often cite a large proportion of the literature on a topic, and literatures with relatively high proportions of review papers will therefore tend to show both lower proportions of citations in the research front and higher proportions of citations to foundational papers.

## RESULTS

### *Reference-Network Graph Analysis*

The reference-network graphs in my study vary considerably, indicating marked variation in the structure of scholarship among the research areas studied. Figure 2, which shows graphs for three extreme cases, illustrates the range of variation.[14] Papers on celestial masers were more likely to cite recently published work than were those on rational expectations or on Toni Morrison's oeuvre, and the rational expectations papers were more likely to cite foundational papers than were papers in the other two areas. Because papers on Toni Morrison's oeuvre infrequently cited other papers in the network, it is difficult to determine if they dispropor-

[14] These graphs show references to forthcoming work as dots beneath the lower boundary and include references associated with literature reviews so that their prevalence is visible (as vertical lines of dots). To aid assessment of the relative densities of references in the three sections of the graphs, I use lines to indicate their research front (R = 40) and foundational papers (F = 20) sections.

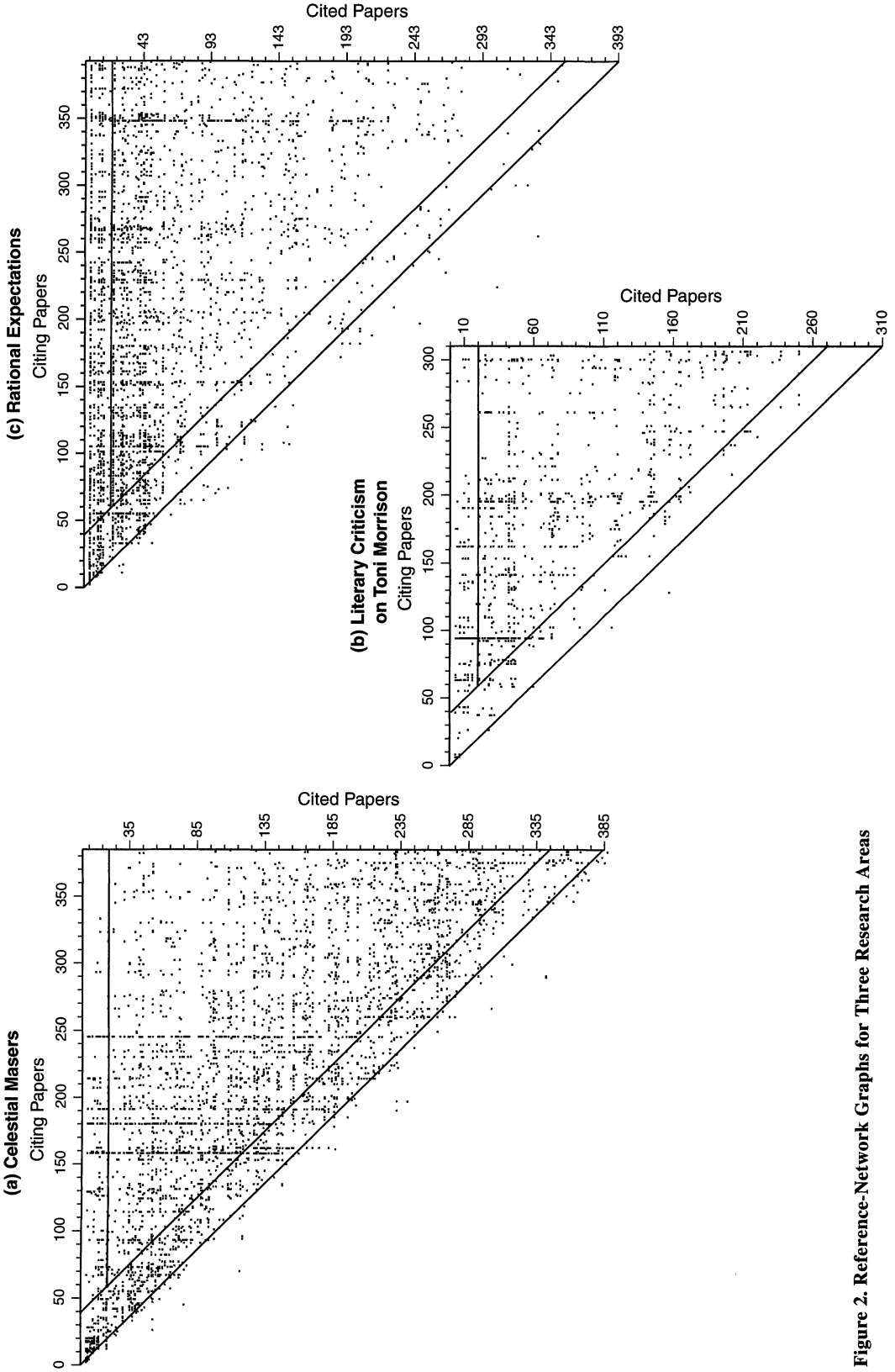


**Figure 2. Reference-Network Graphs for Three Research Areas**

**Table 2. Density Ratios for the Research Front and Foundational Papers, Prevalence of References to the Initial Paper in the Network, and Overall Network Density, in Seven Research Areas**

| Research Area | Density Ratio | | References to Initial Paper in Network (% of Possible) | Overall Network Density |
|---|---|---|---|---|
| | Research Front Papers[a] | Foundational Papers[b] | | |
| Celestial masers | 1.53** | .46*** | 4.7 | .039 |
| Chiral separations | 1.40* | .54*** | 2.0 | .026 |
| Light-front physics | 1.53*** | 1.02 | 30.1 | .076 |
| Literary criticism on Toni Morrison's oeuvre | .41*** | 1.02 | 2.6 | .017 |
| Organizational population ecology | 1.09 | 1.39*** | 70.7 | .134 |
| Rational expectations | 1.03 | 3.21*** | 40.1 | .030 |
| Stroop effect | 1.09 | 1.75*** | 69.5 | .037 |

[a] Density of citations in the research front (R = 40) of the network divided by the density of citations in the "remainder" section of the graph.

[b] Density of citations in the foundational papers section (F = 20) of the network divided by the density of citations in the "remainder" section of the graph.

*$p < .05$ **$p < .01$ ***$p < .001$ (two-tailed tests from random-effects probit analyses)

tionately cited the research front or foundational papers.

Table 2 shows density ratios for the research-front and the foundational-papers sections for all seven reference networks, providing quantitative measures of their patterns of disproportionate citation. The statistical significance of the density ratios' deviations from 1.0, derived from the random-effects probit analyses described above, are indicated by asterisks. These results are easily summarized: (1) The three physical science areas overcite the research front (indicated by RF ratios significantly greater than 1.0), and (2) The three behavioral science areas overcite foundational papers (indicated by FP ratios significantly greater than 1.0). As noted earlier, these conclusions are robust over different specifications of the size of R and F.

The most surprising result in Table 2 is the overcitation of foundational papers shown by the three behavioral science research areas. Price (1970:21) speculated that foundational papers might be slightly overcited in a few "anomalous" areas. But the behavioral science areas' overcitation of foundational papers in Table 2 is substantial, and it seems unreasonable to characterize these three areas as "anomalous." Furthermore, this pattern is inconsistent with Price's conjecture that research areas in the behavioral sciences would show reference-network structures intermediate between those shown by physical science areas (which he claimed would overcite the research front) and humanities areas (which he claimed would not show temporally disproportionate citation patterns). Here, the behavioral science areas exhibit a reference-network structure that is distinct from those of the other research areas.

One component of the high foundational paper reference densities in the behavioral science areas is the high likelihood that subsequent papers will cite the initial paper (see column 3 of Table 2). Indeed, the initial papers in the three behavioral science areas, Hannan and Freeman (1977), Muth (1961), and Stroop (1935), are the most cited papers in their networks. Only the initial paper in the light-front physics literature (Dirac 1949) approaches their citation levels, but even then it is not the most-cited paper in its network.[15] By contrast, the initial papers in the chiral separations, celestial masers, and Toni Morrison literatures were seldom cited. The disproportionate citation of initial pa-

[15] When I asked about the large number of references to Dirac's (1949) paper, a researcher in the area replied, "It never hurts to cite a Nobel Prize winner."

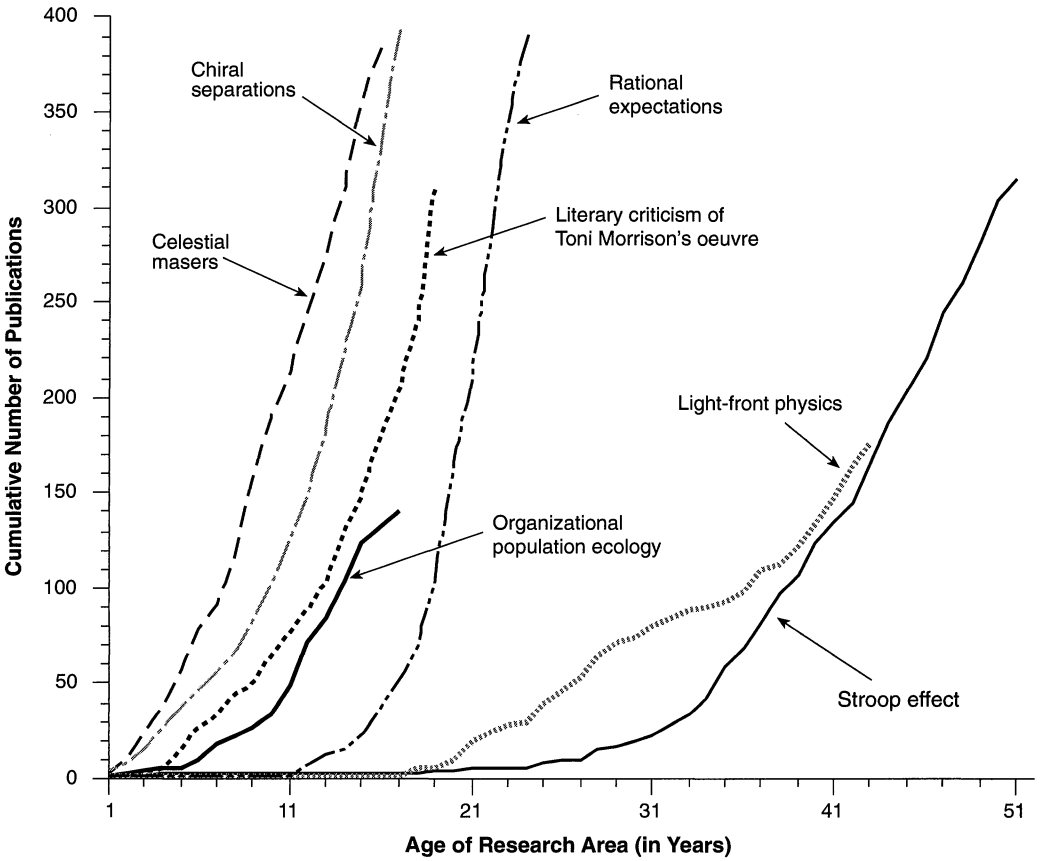


**Figure 3. Literature Growth in Seven Research Areas**

*Note*: The calendar years represented differ across research areas (see Table 1).

pers in the three behavioral science research areas in this study calls to mind the high citation frequencies for "classic" work that Line (1981) reported for entire social science disciplines.

Previous discussions of the structure and development of research areas have suggested that high research-front density ratios should be strongly correlated with other characteristics. For example, Crane (1972:22–26) argued that areas with disproportionate citation of recent work should show an exponential pattern of literature growth (eventually becoming logistic) rather than slow linear growth. Others have suggested that rapidly developing research areas tend to show high citation densities (Mullins et al. 1977), implying that research-front density ratios should positively correlate with overall network citation densities. Neither of these hypotheses is supported by the data for the seven areas I studied. Figure 3, which shows the cumulative growth curves for each area's literature, indicates that four of the areas grew rapidly, while three (light-front physics, organizational population ecology, and the Stroop effect) grew more slowly. However, two of the rapidly growing areas, rational expectations and Toni Morrison criticism, have relatively low research-front density ratios, and one of the slowly growing areas, light-front physics, has a relatively high one. The overall network densities[16] for the seven

[16] Overall network density is the ratio of the number of observed references in each network (including references to forthcoming papers) to the number of possible references in the network, which equals .5 ($N^2 - N$), where N is the number of non-review papers in the network. (Consistent with the RF and FP density ratios, I deleted observations associated with literature reviews from these calculations.)

areas also show no evidence of a strong relationship between network density and the research-front ratios (see column 4 of Table 2); both relatively dense and relatively sparse networks exhibit substantial variation in their research-front values. Thus, the research-front ratios tap a phenomenon that is empirically distinct from literature growth, network density, and network size.[17]

In sum, the results in Table 2 show marked variation in the structures of scholarship among the seven research areas. The three physical science areas cite recent papers to a greater extent than do the other areas, while the behavioral science areas cite foundational papers more than do the other areas. The literary criticism research area is unique in showing undercitation of the research front without overcitation of foundational papers. Network density, network size, and literature growth rates do not explain these patterns. It is worth reiterating, however, that these patterns hold for the periods under study; they need not be permanent features of these areas' development.

What produces the variation across areas? When Price (1970) speculated that research areas vary in their reference-network structures, he expected that they would vary with the temporal horizons of the researchers in a field. In areas that show overcitation of recent work, for example, researchers closely monitor and build upon each others' recent work. In other areas, researchers do not focus their attention on works published at any particular time during the history of the area, thus producing a reference-network graph showing no disproportionate citation of either recent or early papers. A temporal-horizons explanation implies that scholars can change the structure of the reference network they are producing simply by changing where they focus their attention. For example, Price (1970) counseled researchers: "[I]f you want to make [your] field firm and tight and hard and crystalline you have to play with your peers and keep on the ball by citing their recent work" (p. 21).

Another possibility is that the different structures shown in Table 2 may reflect variation across research areas in how researchers use each other's work. For example, if scholars disagree on the relative importance of topics in their area, their papers will have to devote space to convincing others that their work matters. This may require them to relate their research to foundational perspectives in the area. In such cases authors would be expected to link their work to early "classics," giving rise to disproportionate referencing of older papers. Counseling authors in such fields to focus on recently published work neglects the function that references to older papers may fill, and authors will ignore the advice. To address this possibility, I now report results from citation-context analyses.

### *Citation-Context Analysis*

Citation-context analysis examines the text surrounding bibliographic references to determine how scholarly papers incorporate material from earlier works (Latour and Woolgar 1979; Small 1978). Although most citation-context analyses have investigated the rhetorical structure of papers within a single field (e.g., Locke and Golden-Biddle 1997; McCloskey 1985:87–112; Myers 1990), two studies have used the technique to compare papers across disciplines. One of these, Cozzens (1985), compared citations received by two well-known articles, one in neuropharmacology and the other in the sociology of science. She found that subsequent papers initially cited the neuropharmacology article for details of its experimental procedure and findings, but that over time such citations became rare and citations for its main knowledge claim (that the brain has opiate receptors) became frequent. In contrast, scholars rarely cited the sociology of science article for its results, its techniques, or even its main knowledge claim. Instead, they cited it for general themes and speculations that they thought (sometimes mistakenly) it contained. Cozzens (1985) con-

[17] Network density is strongly and negatively correlated with network size for the seven fields in my analysis. Indeed, in the hypothetical case in which all papers contain the same number of references to previous papers in their areas, network density would be a perfect negative and nonlinear function of network size. However, neither network density nor either of its components—network size and per-paper references to other papers—is associated with the research-front density ratios.

cluded that subsequent authors were mainly interested in the general conceptual content of the sociology of science paper, and that its empirical results—the bulk of the article—"were delivered to an empty house" (p. 147).

In the second comparative citation-context analysis, Bazerman (1988:278–88) examined articles published in the 1979 issues of the *American Political Science Review* (*APSR*). He found that the references in these papers were concentrated in lengthy introductory sections where they were used to "establish the literature," a rhetorical undertaking in which authors position their papers in relation to long-standing issues in the field. To accomplish this, political scientists cited relatively old sources. Rather than dealing with specific details of previous works, they typically gave only "brief general characterizations, group characterizations, and simple lists of sources" (p. 283). In a complementary analysis, Bazerman (1988:165–67) examined references contained in five articles on spectroscopy in the 1980 issues of the *Physical Review* (*PR*). In contrast with the *APSR* articles, the *PR* articles discussed in detail results in the papers they cited. Bazerman concluded that difficulty in establishing that their research was important led political scientists to link their research to classic works. Without a theory that could provide a "consistent rhetoric" for their research, authors were forced to construct justifications that "reassemble, reinterpret, and discuss anew wide ranges of the literature, dating back into the discipline's history" (Bazerman 1988:283).

Although Bazerman's (1988) and Cozzens's studies (1985) are based on analyses for only a few papers, their results suggest that examining *how* authors use their colleagues' work can help us understand the results for the reference networks in the present study. In particular, when authors wish to build a case for their work's importance, they tend both to cite previous papers' general thematic content rather than specific results and to cite the foundational papers in a research area. Bazerman's study also reinforces claims that attempts to establish the importance of a paper almost always occur in introductory sections (Locke and Golden-Biddle 1997; Swales and Najjar 1987).

To determine whether the use of previous work varied across the seven research areas I studied, I examined references contained in the introductory sections of papers in each area. Consider the following reference, which appeared in the first sentence of a paper on changes in the number of voluntary organizations:

> A central question in organizational ecology concerns the growth of organizational populations over time (Hannan and Freeman 1977). (Tucker et al. 1988:127)

This sentence asserts that the growth of organizational populations is an important issue in organizational ecology and cites Hannan and Freeman (1977) as evidence for the claim.[18] Citing Hannan and Freeman (1977) orients readers to the general perspective the authors use to frame their research (organizational population ecology), while also supporting the paper's implicit claim of importance (it addresses a central issue within that perspective).

By contrast, consider the initial sentence from an article on celestial masers:

> In a recent article, Weaver et al. [(1965)] reported strong microwave emission lines in the HII regions W3, W49, W51, W75, NGC 6334 and Orion A at a frequency of approximately 1,665 Mc/s.[19] (Weinreb et al. 1965: 440)

The text following "Weaver et al. [(1965)]" reports specific results contained in that paper rather than offering the work as an example of a general perspective. The authors clearly assume that they do not need to tell readers how to think about strong microwave emission at this frequency in HII regions, or why it is significant. When references of this type dominate articles' introductory paragraphs, their authors assume that readers understand the context and im-

[18] Of course, this kind of reference may perform additional functions, such as signaling an author's scholarly allegiance (Stinchcombe 1982) or flattering potential reviewers (see Latour 1987:31–33 for further possibilities). My aim is not to ferret out all the motives underlying references, but to examine the role that references play in justifying a citing paper's importance.

[19] To minimize confusion, I have converted citations in quoted text to *ASR* citation style.

portance of their research topic (Fahnestock and Secor 1988). In contrast, when references such as that contained in the first quotation dominate introductory sections, authors presumably feel the need to provide a context for their research, typically a first step in their attempts to convince readers of their studies' importance (Bazerman 1988; Locke and Golden-Biddle 1997).

My examination of papers' introductory sections revealed a distinctive referencing convention that authors sometimes used to contextualize their work—the listing of papers as examples of a general perspective, methodological approach, or topic. Indeed, authors sometimes signal that the works they are citing are to be understood as examples by prefacing them with "e.g." The following, also taken from the paper on voluntary organizations, illustrates the convention at its extreme:

> Ecological researchers have investigated population growth by studying both processes of organizational foundings and deaths over time ([chronological list of 11 references]). (Tucker et al. 1988:127)

By using this convention, which I call an "orienting reference list" (ORL), authors provide a framework for their work and imply that the framework constitutes an acknowledged scholarly position. In the paper on voluntary organizations, the authors—having previously identified a key question in organizational ecology—now assure readers by citing 11 previous papers that this perspective is an important, or at least a legitimate, approach.

ORLs signal authors' attempts to contextualize and justify their work, and authors often include well-known "classics" in these lists. Thus, the prevalence of ORLs in a research literature should be positively related to the overcitation of foundational papers. To test this expectation, I counted the number of ORLs in the introductory sections of a random sample of 100 papers from each of the seven areas in my study. I defined introductory sections as material preceding "data and methods" or "results" sections,[20] and operationally defined an ORL as a list of at least three papers identified by citing authors as exemplifying a general approach or theme rather than as reporting specific results.

**Table 3. Prevalence of Orienting Reference Lists (ORLs) in Papers, by Research Area**

| Research Area | ORLs per Paper | |
|---|---|---|
| | Mean | Standard Deviation |
| *Behavioral Sciences* | | |
| Organizational population ecology | 1.07 | 1.44 |
| Rational expectations | .57 | .83 |
| Stroop effect | .83 | 1.25 |
| *Other Research Areas* | | |
| Celestial masers | .21 | .65 |
| Chiral separations | .45 | .71 |
| Light-front physics | .34 | .53 |
| Literary criticism on Toni Morrison's oeuvre | .10 | .35 |

*Notes*: N = 100 for each research area. The *t*-value for the difference between the three behavioral science areas and the four other research areas equals 8.26 with 698 degrees of freedom.

Table 3 shows that ORLs were more prevalent in the introductory sections of the three research areas that exhibited overcitation of foundational papers (the behavioral science areas, see Table 2) than in the other four areas. This was due both to the greater likelihood that papers in those areas included an ORL and the tendency of papers with any ORLs at all to have multiple ones. Behavioral science authors often used two or more ORLs to present competing traditions, and then portrayed their work as adjudicating between the competitors (a practice most prevalent in the organizational population ecology papers).

[20] A few papers in the physical and behavioral science research areas (usually short ones) and all of the papers in the literary criticism area, departed from the conventional structure of research articles. For these cases, I examined the entire paper for ORLs. This approach did not appreciably overestimate the prevalence of ORLs in such papers because ORLs rarely appeared outside a paper's first few pages.

Although most ORLs cited relatively old papers, a few cited only recent ones. In these cases authors portrayed their research as addressing a "hot" issue by showing that several papers had recently appeared on the same topic. Of the 100 ORLs in the three physical science areas, 10 were "hot topic" ORLs compared with just 3 of the 257 ORLs in the other four areas ($\chi^2$ test of independence with continuity correction equals 13.59, d.f. = 1). Thus, some of the physical science ORLs contributed to the overcitation of recent publications, whereas almost none in the other areas did so. In general, however, the more frequent use of ORLs in the behavioral science papers contributed to the overcitation of foundational papers shown in Table 2 for the behavioral science research areas.

The dearth of ORLs and the proportionate citation of foundational papers in the Toni Morrison network suggest that authors in that area do not need to make a case for their work's significance. This is consistent with rhetoricians' observations that literary critics usually rely on the eminence of the authors they analyze to justify the importance of their papers (Fahnestock and Secor 1988:440).

Examining how subsequent papers cited the initial articles in each of the seven reference networks reinforces the results shown for ORLs. The initial articles in the celestial masers, chiral separations, and Toni Morrison literary criticism areas were each cited by fewer than 20 subsequent papers. The celestial masers and chiral separations articles initially were cited for specific details of their results—see the citation of Weaver et al. (1965) above—but later were cited primarily in literature reviews as being the first publication in their areas. The first Toni Morrison literary criticism paper was never cited for its temporal priority; being the first to analyze a particular author apparently earns one little recognition among literary critics.

In contrast, the initial papers in the three behavioral science areas were cited much more than would be expected by chance, and citations to those papers contributed to the overcitation of the foundational-papers sectors in their research literatures. Examination of citations to these papers shows that authors cited them primarily as totemic representations of the general approaches they initiated rather than for any results they reported. For example, 64 percent of the citations to Muth (1961) referred to generalities such as "rational expectations in the sense of Muth" or the eponymic "Muthian rational expectations" rather than giving information about what this concept means or what Muth said about it. Similarly, 61 percent of the citations to Stroop (1935) referred only to such generalities as the "Stroop phenomenon," "Stroop interference," or (beginning in the 1970s) the "Stroop paradigm," rather than giving any information about the results or techniques that Stroop's paper reported. Over time, citations to Muth (1961) and Stroop (1935) became highly standardized, almost as if authors shared boilerplate text for citing them. Finally, 53 percent of the citations to Hannan and Freeman (1977) credited it as representing organizational population ecology but gave no further details about the paper or perspective (the Hannan and Freeman paper was much more likely to be included in an ORL than either Muth's or Stroop's papers).

Among the fields showing undercitation of foundational papers, only in light-front physics was the initial paper often cited as exemplifying a general approach or perspective. Twenty-six percent of the citations to Dirac (1949) were of this type, about half of which were contained in ORLs. This pattern is probably due to light-front physics' status as a minority approach within nuclear physics (see Appendix A); by citing his paper, authors use Dirac's status as one of the foremost physicists of the twentieth century to help establish the legitimacy of their theoretical framework.

In sum, both variation in the prevalence of ORLs across research areas and in the number and types of citations to the initial papers suggest that differences in how authors use the previous literature can help account for the results of the reference-network analyses presented above. In particular, when authors face the burden of providing readers with a context for interpreting and legitimating a paper, they tend to cite previous work, but cite it for its thematic content rather than for details of results or methods. Well-known papers are likely to be cited in

such instances because their visibility makes them shorthand "markers" of general perspectives. Papers published early in the development of a research area are likely to be well known, leading to the observed associations between the overcitation of foundational papers in a reference network and both the prevalence of ORLs and citation of previous work for general rather than specific content.[21]

## CONCLUSION

I have shown that the structure of scholarship, as manifested by the temporal pattern of references in a reference network, varies substantially across research areas and that this variation is at least partly due to differences in how scholars use their colleagues' work. Following Bazerman (1988), Fahnestock and Secor (1994), and Locke and Golden-Biddle (1997), I suggest that authors' use of the literature varies depending on the tasks they must carry out to write papers that colleagues will see as significant contributions. For example, when authors need to contextualize their research and build a case for its significance, they often try to show that they are addressing longstanding issues of broad interest. Using ORLs helps authors achieve this goal, and the fact that authors in the behavioral science research areas I studied frequently used ORLs suggests that they could not assume that their readers would appreciate the contextual importance of their research. According to this interpretation, the less frequent use of ORLs in the physical science and literary criticism areas suggests that authors in those areas could assume that their readers would understand their papers' significance.

Although my results do not prove the validity of this line of interpretation, they suggest two conjectures about the kinds of patterns that one would observe if this approach is correct. First, reference networks exhibiting low citation densities are also likely to exhibit undercitation of recent work. I believe that this pattern results when scholarship in a research area is "individualistic" in the sense that scholars often represent their work as the product of personal insight or experience rather than as an extension of other researchers' work. This pattern characterizes scholarly literary criticism on Toni Morrison's oeuvre, which may exemplify (in the extreme) Whitley's (1984) concept of a "fragmented adhocracy"—a field in which scholarly research involves both low mutual dependence and high task uncertainty (Collins 1975: 506–14; Fuchs 1992).

Second, overcitation of both foundational and recent papers in a reference network are unlikely to occur simultaneously. As argued above, the former usually means that authors need to convince readers that their work matters, and thus indicates a lack of agreement among scholars on the relative importance of research topics. Frequent citation of foundational documents is more a sign that researchers are enlisting the authority of their field's founders to persuade skeptical readers that their work is important than it is an indication of researchers' hesitance to forget their field's founders. Overcitation of recent papers, on the other hand, is likely to occur when authors focus on specific details presented in previous papers, which usually presupposes a level of agreement on the importance and meaning of research findings that makes citation of early work for thematic or programmatic material unnecessary.

Although my results do not allow an assessment of claims about factors that foster or inhibit agreement about the meaning and significance of research results (e.g., see Cole 1992; Collins 1994; Fuchs 1992; Pfeffer 1993), they do suggest that characteristics of scholarly communities affect how authors craft their research papers. In this respect they are inconsistent with the model of scholarly development suggested by Cole (1983, 1992), who argued that at their research frontiers, scientific fields do not differ significantly. Cole contrasted the research frontier of a field, which he defined as "all the work currently being produced by all active researchers in a given discipline," with "core knowledge," the theories, methods, and results that researchers in the field widely accept (Cole 1992:15). Based on evidence about the kinds of material cited in

[21] This line of reasoning also suggests that citation of previous papers for their specific content is associated with overcitation of the research front. I am currently gathering data to evaluate this hypothesis.

college textbooks, Cole claimed that the natural sciences exhibit stable and coherent core knowledge, while fields like sociology do not. But he argued that the research frontiers of *all* fields are characterized by controversy and low consensus, which in turn produces similar behavioral patterns. The substantial differences in reference-network structures suggest significant differences across research areas in how scholars behave at the research front, and the citation-context analyses suggest that these differences flow from different patterns in how authors use past research. Together, these findings suggest that variation in core knowledge across fields leads to variation in scholars' behavior at the research front.

Although results from seven research areas hardly suffices for inferring broad disciplinary differences in the structure of scholarship, they do point to the fruitfulness of studying how scholars use their colleagues' work as a tool to better understand other kinds of variation across scholarly communities. For example, researchers studying scholarly communication systems have found that compared to the physical sciences, the behavioral sciences seem less effective in disseminating knowledge. Based on an extensive study of communication patterns in the physical and social sciences, Garvey, Lin, and Nelson (1979) concluded that the information systems of the social sciences are more time-consuming and less efficient. For example, they report that publishing in scholarly journals takes longer in the behavioral sciences not because behavioral scientists work more slowly but because peer review in the behavioral sciences takes longer and because behavioral science journals take longer to publish accepted papers (Garvey et al. 1979:283–86). Other studies have found that journal structures in the behavioral sciences are more diffuse than those in the natural sciences (Hargens 1991; Stevens 1953), exacerbating information-retrieval problems.[22] Manuscript-rejection rates for behavioral science journals are significantly higher than those for natural science journals (Hargens 1988; Zuckerman and Merton 1971), and larger proportions of the papers published by major behavioral science journals have previously been rejected by other major journals (Garvey et al. 1979:284–86).

Given the centrality of communication in any scholarly field, why do behavioral scientists tolerate such apparent disorganization? One possibility is that behavioral scientists tend to use their colleagues' work differently than natural scientists, and that these use patterns mitigate the costs they incur for a seemingly inefficient communication system. When scholars are oriented to the general thematic content of previous work rather than to concrete details of techniques and results, it is less important to have a communication system that gets papers into print rapidly and in a manner that facilitates information retrieval. Instead, scholars may prefer that their journals play other roles, such as screening out all but a few high quality submissions or devoting substantial space to reviews of recent monographs. The effectiveness and efficiency of a scholarly communication system should depend on the typical uses to which researchers put each others' work, and systems that work well under one kind of use pattern may be poorly suited to others.

This is but one example of how information on how researchers use their colleagues' work may provide insights for understanding variation in other aspects of scholarly activities. Studies of patterns of literature use in other research areas are likely to reveal additional structures of scholarship beyond the three reported here and would provide a fuller picture of both the dominant types and their range of variability. Given information on the structures of scholarship in a range of research areas, we could begin to investigate the extent to which they covary with other patterns of scholarly behavior, such as competition for priority and the use of secretive strategies to avoid being scooped (Hagstrom 1974). In combination with longitudinal studies of how structures change over time, studies of reference networks for additional research areas should illuminate both the causes and consequences of those structures.

[22] A diffuse journal structure is one in which journals tend to be similar in size. By contrast, in a concentrated journal structure journals vary greatly in size, often with a single journal publishing a majority of all papers.

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## APPENDIX A. SHORT DESCRIPTIONS OF THE RESEARCH AREAS IN THE ANALYSIS

### *CELESTIAL MASERS*

In 1965 astronomers studying areas of ionized hydrogen in space detected extremely bright microwave radiation with striking and unexpected properties. Astronomers soon decided that this radiation must be maser emission from interstellar hydroxyl ("maser" is an acronym for "microwave amplification by stimulated emission of radiation"). Subsequent research detected other molecules that exhibit maser emission, developed models of how maser emission is produced in various astrophysical environments, and cataloged the distribution of maser sources in the heavens. Elitzur (1995) gives an accessible account of this research area.

### *CHIRAL MOLECULES*

I use "chiral molecules" as a shorthand term for "high performance liquid chromatographic separation of chiral molecules." Many chemical compounds come in two forms—one the mirror image of the other. These compounds usually occur as mixtures of the two forms, and for many years there were no effective methods for separating the two forms of most chiral molecules. Many pharmaceuticals are chiral molecules, and because the human body is a highly chiral environment it often responds differently to each form of a given chiral molecule. Developing methods of separating the two molecular forms is important both for enhancing the desired effect of one form of a drug, and for avoiding the possible ill effects of its mirror-image form. Research on liquid chromatographic techniques for separating chiral molecules increased rapidly during the 1970s and 1980s. For a history of this area, see Pryde (1989).

### *LIGHT-FRONT PHYSICS*

Light-front physics is a research area in theoretical nuclear physics. Participants trace its origin to a 1949 paper by P. A. M. Dirac showing that physicists can use any one of at least three frameworks to represent interactions between nucleons. One of these frameworks, the light front, is the three-dimensional surface in space-time formed by a wave front advancing at the velocity of light. Researchers in this area believe that using the light-front framework (also known as "null plane dynamics") facilitates representing and understanding nuclear interactions. Research on this topic proceeded in fits and starts until the mid-1980s; since then the area has seen an upsurge of activity. The light-front approach remains a minority approach to nuclear theory, however, with most theorists using the "lattice theory" approach.

### *LITERARY CRITICISM ON THE WORK OF TONI MORRISON*

Toni Morrison's novels began attracting significant attention from literary critics in the mid-1970s. I include here only the work of academic literary critics whose writings appeared in scholarly books and journals—not the reviews of her novels that appeared in newspapers, mass circulation magazines, and book-review serials. Academic literary critics are interested in Morrison's work partly because it raises issues of race and gender that have become important areas of academic analysis, and partly because Morrison's multivocal style and use of ambiguity provide substantial opportunities for critical analysis (Fahnestock and Secor 1994; Griswold 1987).

### *ORGANIZATIONAL POPULATION ECOLOGY*

Organizational population ecologists study changes in the number of functionally similar organizations in a society, for example, the number of banks or breweries. Changes in organizational population size are viewed as stemming from basic structural constraints (e.g., legitimation, competition, and organizational density), and researchers evaluate formal models of how these constraints jointly affect organizational populations. Links between formal models and analytic techniques are typically quite close, and papers in this area often exhibit considerable mathematical and statistical expertise. According to Newman (1993), this line of research is "perhaps the nearest thing to a paradigm in contemporary sociology" (p. 277).

### *RATIONAL EXPECTATIONS*

Researchers in rational expectations built upon an early paper (Muth 1961) formalizing how economic actors might form expectations about the future, to develop formal macroeconomic models. The rational expectations approach is often credited with providing a logically coherent basis for macroeconomics that its predecessor, Keynesian economics, lacked. In addition, many of the proponents of the rational expectations approach argued that it shows that macroeconomic policy interventions by the federal government are unlikely to have the effects that policymakers desire. Few papers in this research

area analyze empirical data; many present formal economic models and examine their implications. In 1995 Robert Lucas received the Nobel Prize in economics for his work in this area. For an overview, see Maddock and Carter (1982).

### *Stroop Effect*

In 1935 J. R. Stroop reported experimental results showing, for example, that people read the word "red" more slowly when it is written in green ink than in black ink. Stroop was interested in the general phenomenon of interference, and many of the early papers following his approach sought to determine the generalizability of his results across different kinds of tasks, personality types, and so on. Cognitive psychologists are interested in the Stroop effect because it may offer clues about primitive operations of the brain and the process of attention. For an overview, see MacLeod (1991).

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